The Determination of the Microphysical Characteristics of Aerosols in the Lower Part of the Marine Atmospheric Boundary Layer from the Structure of the Backscattered Lidar Signal

Kusiel S. Shifrin
College of Oceanic and Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-5503
phone: (541) 737-2016 fax:(541)737-2064 email: shifrink@ucs.orst.edu

Ilia G. Zolotov
College of Oceanic and Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-5503
phone: (541) 737-5220 fax:(541)737-2064 email: zolotovi@ucs.orst.edu
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LONG-TERM GOAL

Our long-term goal is to establish reliable relationships between the environmental factors (such as wind, waves, humidity, etc.) and the aerosol optical properties in the lower part of the marine atmospheric boundary layer (LP MABL).

SCIENTIFIC OBJECTIVES

Our scientific objective is to learn how to use horizontal lidar measurements over the sea surface for obtaining the aerosol particle size distribution (APSD) in LP MABL. For this purpose we develop a method for inverting the spectral attenuation of atmospheric aerosol determined from lidar data into APSD. In order to investigate spatial-temporal irregularities of the atmospheric aerosol, we intend to analyze experimental lidar data in corroboration with the group of Dr. S. Sharma of the Hawaii Institute of Geophysics and Planetology.

APPROACH

The horizontal backscattered lidar signal (BLS) depends primarily on the optical characteristics of atmospheric aerosol. In the single-scattering approximation, the dip in BLS is governed by backscattering β and attenuation σ coefficients of aerosol in a given atmospheric layer. This year, we have developed and analyzed a method for retrieving the aerosol particle size distribution (APSD) from the above optical characteristics as obtained from lidar observations at one or two wavelengths. We were also interested in how the retrieval results depend on the lidar working wavelength. The method we are developing is based on the up-to-date knowledge of aerosol in LP MABL. According to numerous studies (see, for example, [1,2]), the APSD in LP MABL can be described as a sum of three components, each having a lognormal distribution with modes widely spaced. The variances of the components do not take very small values; in other words, there are no narrow peaks in APSD. The relative concentrations of the components are spaced approximately evenly when taken in the logarithmic scale.

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WORK COMPLETED

We developed and investigated an algorithm for inverting the aerosol optical parameters σ and β obtained from BLS into APSD [3,4]. The algorithm is as follows:

- A wide parameter interval for the three aerosol components is specified and quantized;
- An interval of acceptable errors for the sought-for optical characteristics β_i and σ_i is preset;
- APSDs are constructed for every quantized interval for all combinations of the parameters in the given interval;
- All possible parameter combinations of APSD components are taken from the given quantized parameter interval, and APSD models are constructed for every combination.
- Optical characteristics of the constructed APSDs are calculated and compared with the initial β_i and σ_i.
- The models whose optical characteristics fall within the preset error interval for β and σ are considered as satisfying the initial data.
- Mean, maximum and minimal ordinates of APSDs of suitable models are calculated.
- The model closest to the mean ordinates is selected. This model is assumed to be the most probable APSD satisfying the initial data.

The initial interval of APSD parameters was chosen so that it would surely span the interval of APSD parameters for all cases of the marine aerosol, whether observed or theoretically constructed. The modal radius a_k and variance s_k for the three components of the marine aerosol are presented in Table 1.

Table 1.

Component	a_k	s_k
1	0.025 - 0.055	0.10 – 0.75
2	0.15 – 0.75	0.10 – 0.75
3	5.4 – 15.0	0.05 – 0.70

The parameters were quantized evenly in such a way that the interval of a_k had 25 points and the s_k interval had 27 points. The relative concentration of the second component c_2 was chosen from the 0.001 – 0.75 interval (12 points on an approximately logarithmic scale); the relative concentration of the third component c_3 was chosen from the 10^{-5} – 10^{-3} interval (12 points on an approximately logarithmic scale). The total number of particles was chosen from the 50-2000cm^{-3} interval (10 points on an approximately logarithmic scale).

We examined the above-described algorithm for its stability to the initial data and to the lidar wavelength. For this purpose, we calculated the error of the most probable APSD for different particle size intervals, and the error of the spectral attenuation of this APSD for different spectral ranges. We used this algorithm for different models and for lidars of different wavelengths. In what follows we shall give some examples of how the method works. Table 2 presents the errors (%) of APSD retrieval for different particle radius intervals for four cases.

Table 2.

Case		0-30.0μm		0.1-30.0μm		0-20.0μm		0.1-20.0μm	
		δ_p	δ_i	δ_p	δ_i	δ_p	δ_i	δ_p	δ_i
I	a	27	16	23	16	28	16	23	16
	b	24	12	20	12	24	12	21	12
II	a	32	17	28	16	34	18	30	18
	b	30	12	26	12	32	12	26	12
III	a	28	47	25	47	21	16	18	16
	b	39	60	30	61	31	19	21	18
IV	a	17	24	15	24	15	13	12	13
	b	38	27	23	26	38	19	22	19

Case I. The initial model parameters: $c_1 = 0.98992$; $a_1 = 0.04238$; $s_1 = 0.35$; $c_2 = 0.01$; $a_2 = 0.4606$; $s_2 = 0.4$; $c_3 = 0.8 \cdot 10^{-4}$; $a_3 = 9.8$; $s_3 = 0.18$; $N = 400$ cm^{-3}. The optical parameters were obtained for two lidars at $\lambda_1 = 0.55$ μm and $\lambda_2 = 10.59$ μm.
Case II. The same initial model for a single lidar at $\lambda = 0.55$ μm.
Case III. The same initial model for two lidars at $\lambda_1 = 0.532$ μm and $\lambda_2 = 1.06$ μm.
Case IV. The initial model: $c_1 = 0.66661$; $a_1 = 0.02846$; $s_1 = 0.4$; $c_2 = 0.33331$; $a_2 = 0.2041$; $s_2 = 0.35$; $c_3 = 0.8.10^{-4}$; $a_3 = 9.5$; $s_3 = 0.2$; $N = 600$ cm^{-3}. The optical parameters were obtained for two lidars as in the Case I.

The rows a) and b) correspond to two different samples from the initial model parameter interval. The row a) corresponds to odd quantization numbers; the row b), to even ones. δ_p is the mean relative value of the absolute difference between the obtained and initial distributions calculated over the quantization points of the particle radius. δ_i is the same quantity obtained by integrating over the radius interval. The latter is characterized by a greater effect of the difference between the initial and obtained APSD for large particles.

Table 3 presents the errors (%) of spectral attenuation in different spectral ranges for the models corresponding to those in Table 2.

Table 3.

Case		0.45-15.0μm	0.45-1.06μm	3.0-5.5μm	7.9-15.0μm
I	a	1.8	1.9	2.0	2.1
	b	1.6	2.8	1.2	0.6
II	a	5.7	2.5	6.5	8.2
	b	2.4	3.5	1.7	1.2
III	a	5.3	0.7	2.0	12.3
	b	5.0	0.6	2.6	11.3
IV	a	2.1	2.5	2.4	1.6
	b	3.8	1.7	6.6	3.4

The figure shows the inversion results for the case I.

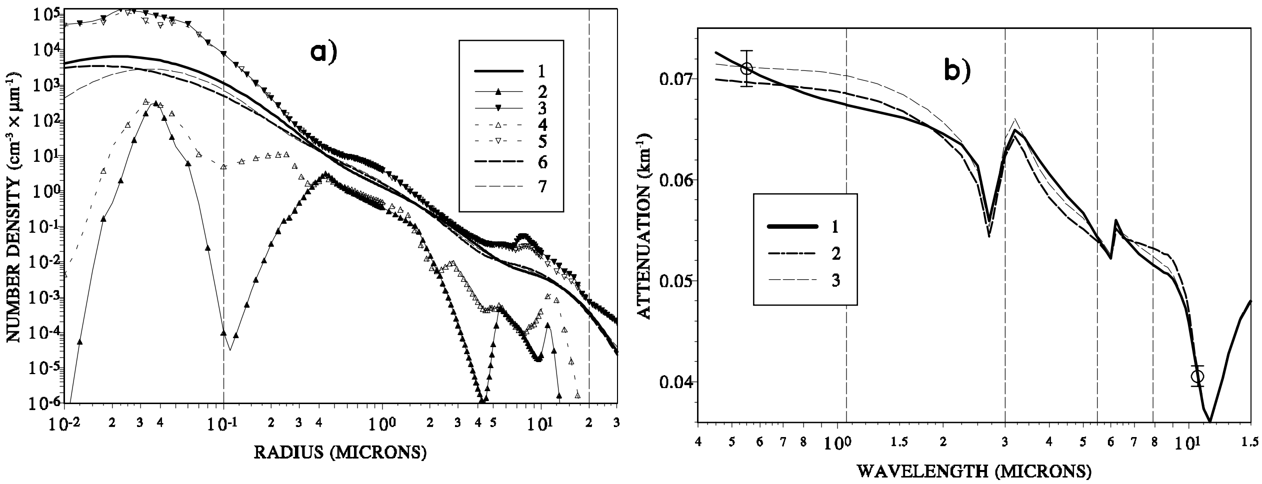

Figure a): APSD; 1, initial APSD; 2,3, minimal and maximum ordinates for the sample from odd quantization numbers; 4,5, minimal and maximum ordinates for the sample from even numbers; 6,7, the most probable APSD for the odd and even samples respectively. **b):** the spectral attenuation σ; 1, initial σ; 2,3, σ calculated for the most probable APSD from the odd and even samples respectively.

The results show that the suggested method of choosing the most probable model yields an accuracy which is comparable with the inversion accuracy for the spectral attenuation by the constrained method, with the chosen most probable models having the same smoothness properties as the models obtained by the constrained method. It should be considered that initial information supplied by lidar is significantly less than what is needed for the inversion by the constrained method.

It is essential in our case that along with the most probable solutions, we obtain other, possibly "false" solutions (the areas between the curves 3-4 and 5-6), which also satisfy the initial lidar data. However, these solutions yield a much greater retrieval error for the spectral attenuation (up to 20%) in the 0.4-15 μm spectral range. Additional information is necessary in order to eliminate these solutions. It is necessary to emphasize that a sufficiently wide interval of model parameters from which the solution is selected is mandatory for ensuring a good most probable solution. When narrowing this interval unjustifiably, one gains in computer time significantly, but risks to obtain false solutions.

The case III has been considered in anticipation of a lidar with λ = 1.06 μm to be included into the measurement scheme of the Hawaii Institute of Geophysics and Planetology in addition to a lidar with λ = 0.532 μm. As it is seen from Table 2, this will make it possible to invert experimental data successfully.

We analyzed the data obtained by the experimental group of the Hawaii Institute of Geophysics and Planetology for a single lidar of λ = 0.532 μm [5]. Two types of spatial irregularities were revealed; those of the 10-15 m dimension and of 250 m. A correlation was established between large irregularities and typical dimensions of convective eddies over the sea surface. Smaller irregularities have a more complex nature. Further studies are needed.

RESULTS

1. It was shown that the method of obtaining APSD from lidar data works successfully. The accuracy of APSD retrieval is comparable to the constrained method of inverting the spectral attenuation in a limited spectral range.
2. It was shown that lidar measurements make it possible to observe spatial irregularities of the marine aerosol, which are closely correlated with convective eddies over the sea surface.

IMPACT/APPLICATION

There are grounds to believe that the method we develop for obtaining APSD from lidar data is promising. In spite of the fact that lidar measurements yield information only for individual wavelengths, the inversion accuracy turned out to be of the same order as in "traditional" methods. This opens new prospects of using lidar in future studies of marine aerosol. The analysis of the efficiency of our method resulted also in formulating certain requirements to lidar observations (such as the optimum number of measurement wavelengths, attendant observations, etc.) which can be applied when planning next experiments.

TRANSITIONS

Our method is in use in our joint work with the experimental group of Dr. S. Sharma of the Hawaii Institute of Geophysics and Planetology. It has been used by Dr. P. Bruscaglione, Istituto Fisica Superiore, Italy, for the study of the atmospheric aerosol near the sea surface; by Dr. O.V. Kopelevich, Institute of Oceanology of the Russian Ac. Sci., for the study of hydrosol; by Dr. I.M. Levin, Institute of Oceanology of the Russian Ac. Sci., for the study of the aerosol near the sea surface.

RELATED PROJECTS

We will use our method in the NASA-funded work "The improved algorithm for estimating the atmospheric effect in space measurements of the chlorophyll concentration." We are going to apply the same approach to the inversion as in this work.

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